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Analysis of Errors Made by Students Solving Genetics Problems

by

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April, 1984

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ABSTRACT

The purpose of this study was to analyze the errors made by students solving genetics problems. A sample of ten non-science undergraduate students was obtained from a private college in Northern New Jersey.

The results support prior research in the area of genetics education and show that a weak understanding of the relationship of meiosis to monohybrid and dihybrid cross problems interferes with the ability to develop meaningful solutions. Furthermore, successful algebraic manipulations do not ensure an understanding of gamete genotypes and random segregation of chromosomes is often not understood.

Analysis of Errors Made by Students Solving Genetics Problems

Introduction

College and high school students frequently postpone biology until their senior years because they were unsuccessful in understanding high school biology or possess the notion that biology is "easy" (Douglass, 1979). They also tend to take biology courses to fulfill the science requirement in order to avoid chemistry or physics. The fear of mathematics and logical reasoning is very real to a senior who needs only 6 more credits in science courses to graduate. Such people would currently be termed scientifically illiterate.

Valuable mathematical insights and motivations are often withheld from biology students (for fear of frightening them); and, likewise, mathematics students are frequently scornful of biology because they imagine it as a mindless memorization course. Admittedly, descriptive biology is in too many instances taught in such a way as to roundly justify the complaint that it lacks intellectual dimension (MacDonald, 1971). Problems in Mendelian genetics and those concerning Hardy-Weinberg Equilibrium require mathematics that is not beyond the scope of that taught in high school. It is important that students see realistic applications of high school mathematics (Austin, 1977). For example, latin squares are used in the biology classroom in teaching the segregation of traits according to the laws of Mendel for dihybrid crosses (MacDonald, 1971).

Genetics provides an especially apt area of biology in which to motivate students to apply mathematical models; for example, a model that shows an analogy between disjunction in truth tables and Mendelian trait segregation to define phenotypes. Mendelian trait segregation tables can lead to other mathematical models, motivating students to search for other mathematical analogies on their own initiative (MacDonald, 1971).

Herein lies a number of problems that the instructor must solve in order to teach those students that are so-called scientific illiterates who fear mathematics and subjects that lend themselves to symbolic or abstract

representations. It would be prudent for the instructor to provide materials suitable for a variety of intellectual levels and cognitive styles. Perhaps an assessment of the concepts themselves and the spatial and logical skills necessary to master the concepts is in order. If this information were at hand, then the instructor could organize a teaching strategy that would enhance understanding and lead the student to the point where concepts could be applied.

Mertens (1971) raises the question about organizing teaching materials for meiosis and Mendelian laws. It seems that Mendel's principle of segregation is more readily grasped intuitively or without a detailed understanding of meiosis than is his principle of independent assortment. Students do not understand that gametes are haploid and that somatic cells are diploid, even though they may not understand the details of meiosis. Interestingly, students tend to understand Mendelian ratios apart from an understanding of meiosis. Teaching meiosis first results in Mendelian genetics being much less abstract, much less a matter of pure probability and mathematical theory. According to Mertens, most students seem to find genetics abstract enough without increasing its abstraction by presenting Mendelism without a cytologic basis.

The purpose of this paper is to present an analysis of errors that occurred on certain types of genetics problems. And although the sample is small, the author believes that is is representative of larger groups of students experiencing similar errors.

METHODS

The data for this exploratory project was obtained under actual testing conditions during an evening summer session course given at a private undergraduate school in Northern New Jersey. The students taking this course were non-science majors with one exception; a talented high school student was taking the course to prepare herself for exposure to undergraduate work. The course, Introduction to Biology, was scheduled for approximately 24 meetings, each 2½ hours long. During this time the students took 4 tests - all untimed but not to exceed 2½ hours. Questions from two of these 4 tests are used here to examine students' responses to genetics questions. The questions follow.

The 2n of a hypothetical organism equals 8 chromosomes:

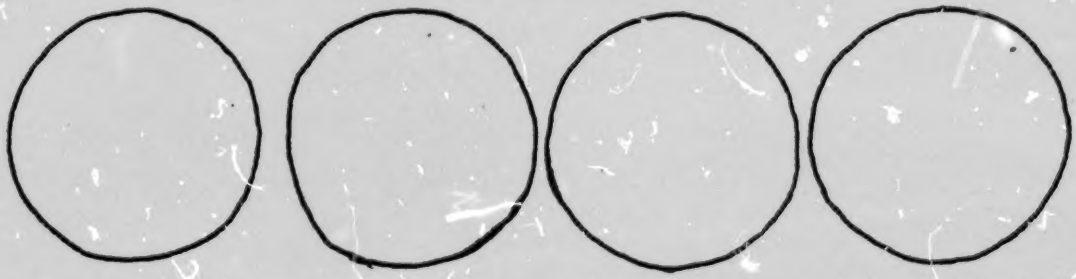
1. How would these 8 chromosomes be arranged in a sex cell undergoing metaphase I of meiosis? Draw in the space below. Enclose your drawing in a cell membrane

[Insert workspace]

2. How would these chromosomes appear during metaphase II of meiosis? Draw in the space below. Enclose your drawing in a cell membrane.

[Insert workspace]

3. What would I find inside the following four cells that result from telophase II of meiosis? Make sure that I can see and count the chromosomes you draw.



4.

Pp	Pp
Pp	Pp

Note: PKU is a homozygous recessive disease.

Given the possible genotypes as shown in the Punnett square above, determine the genotypes of the gametes (the egg and the sperm) donated by the female and male parent.

5. Given that the genotype of a pea plant having purple flowers is Ww, label the pair of homologous chromosomes accordingly. Use the symbols:

W = dominant = purple
w = recessive = white

6. A couple are trying to decide what the probability of their having a hemophiliac son will be. The husband's mother is normal and his wife is a carrier. You determine the probability. Show me your work in the space provided or on a worksheet. Remember that hemophilia is a sex-linked disease.

Questions 7 - 9

A woman who is heterozygous for free-earlobes and homozygous recessive for curly tongue marries a man who is homozygous dominant for free-earlobes and heterozygous for curly tongue.

7. What are the possible gamete combinations that can be made by each parent. (To say it another way: What are the possible genotypes of the sperm and the egg.)

8. Make a Punnett square to show how the possible genotypes of the sperm and the egg combine.

9. What is the phenotypic ratio for this cross? (Remember, the phenotype is what you can see.)

10. Which of the following is a CORRECT representation of the complete Hardy-Weinberg equation?

(A) $p^2 - q^2$
(B) $p^2 + q^2$
(C) $p + pq + q$
(D) $q^2 + pq + q^2$
(E) $p^2 + 2pq + q^2$

11. The frequency of allele A in an ideal population is 0.6. What is the percent of heterozygotes in this particular population?

(A) The data given is insufficient to solve this problem
(B) 24%
(C) 40%
(D) 48%
(E) 96%

RESULTS AND CONCLUSIONS

The following table summarizes the students' responses to the aforementioned problems

Question#	Boyle	Cotter	Corvey	Rovetto	Priore	Dorsey	DeSciscio	O'Toole	Feliciano	Fadden
1	+	-	+	+	+	-	+	+	+	+
2	-	-	-	+	+	-	-	+	+	+
3	-	-	-	-	+	-	-	+	-	-
4	-	+	-	+	+	+	+	+	-	+
5	-	-	+	-	+	+	-	+	-	-
6	-	-	-	-	-	-	-	+	+	-
7	-	-	-	-	+	+	-	+	+	+
8	-	-	-	-	+	+	-	+	+	+
9	-	-	-	-	-	+	-	+	-	-
10	D	E	E	E	E	E	E	E	E	E
11	A	A	D	D	D	D	D	D	D	A

+ correct
- incorrect

It is reasonable to suspect a descending trend on the meiosis problems (1-3) as one would not expect a student to get a latter problem correct without having been able to do the former problem. I was not surprised to see that the "homologous chromosome" problem (5) was generally difficult. This seems to indicate that students can still make correct drawings to depict chromosomes at various stages in meiosis and have no inkling as to the relationship between genes and chromosomes.

For problem 1, a student simply put all the 8 double-stranded chromosomes in a circle. One case for problem number 2 showed a 4 by 4 matrix of double-stranded chromosomes.

The answers for problem number 3 included the following variations.

- four cells dividing into 8; no chromosomes shown
- each cell had only one single-stranded chromosome in it.
- each cell had 2 double stranded chromosomes in it.

To see that 8 out of 10 students were able to work the monohybrid problem (4) under those particular conditions was slightly surprising. Given the data of the possible genotypes of the offspring, the students were able to develop the parent genotypes. It would be interesting to see the results of a problem of similar design for a dyhybrid cross.

A common mistake in working problem number 4 was to assign, for example, PPPp to a parent instead of Pp. A very different response came from a student who expanded the 2 by 2 matrix into a 4 x 4 (the student simply added 3 more Punnett squares to the one already there.)

Obviously, the sex-linked problem (6) was difficult. The most frequent mistakes that students made were to try to work the problem by using symbols for traits only and neglecting the sex chromosomes, putting symbols on the Y chromosomes, or assigning one symbol to an XX and one symbol to an XY.

The fact that 5 out of 10 students worked problems 7 and 8 correctly and that they were the same students is certainly likely. It is obvious that a dihybrid cross cannot be worked properly without knowledge of the parent genotypes and parental gametes. The most common error for problem 9 was to provide the genotype instead of the phenotype.

It is interesting to see that 9 out of the 10 students were able to recognize the Hardy-Weinberg equation and 7 out of 10 able to apply it. (problems 10 and 11). Yet, the other problems that perhaps could be solved via a rule method appear to present different degrees of difficulty. I recognize, however, that for some of the other problems the rule is not presented and the student is required to know it versus searching through five options for the correct equation as in problem 10.

In summary, many of the errors in thinking that occurred on these genetics problems are similar to those discussed in the article by Stewart (1982). The results in this paper support Stewart's claim that the students' weak understanding of the relationship of meiosis to monohybrid and dihybrid cross problems interferes with their ability to develop meaningful solutions. It also supports the fact that successful algebraic manipulations do not ensure an understanding of gamete genotypes nor their origin. And, although my students could demonstrate combinatorial ability, not all could relate random segregation of chromosomes to dihybrid crosses - as Stewart had observed.

Significance

It would appear that the improvement of science instruction and resultant learning outcomes require continual attention in order to develop strategies of instruction to aid the learning of a particular set of concepts or skills. More developmental and research efforts should be applied in this area. Some attention should be given to ensure that students of varying skills and abilities are provided with means of improving these skills and abilities. In this case, less abstract and more concrete examples may be needed by some students. The importance of developing specific instructional strategies that will improve student problem-solving strategies which should in turn improve logical thinking ability in university students cannot be emphasized enough.

Perhaps the development of an instructional strategy that is compatible with cognitive development and acquisition of spatial skills for an introductory genetics course would help overcome students' anxieties toward problem-solving and provide both students and teachers with more rewarding experiences.

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